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An Experimental Investigation on Performance Analysis of CI Engine and Environmental Impact by Combustion of Hydrogen as an Additive Gas with Diesel Fuel

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Abstract-:Hydrogen may one day replace fossil fuels as the primary energy source, one that lessens our dependency on limited fossil fuel reserves while cutting down on emissions from automobiles. The findings shown reveal that converting to dual-fuel mode improves thermal efficiency and the consistency of combustion while lowering CO emissions and waste products. Hydrocarbon emissions, fuel consumption, and diesel fuel igniting by a negligible amount. The most recent research results on hydrogen blending with diesel fuel in internal combustion engines are presented here. Hydrogen-powered cars had their basics laid out, the engine's unique characteristics examined, and the appropriate literature assessed.

Keywords:*Hydrogen, emissions, analysis, ICM, environmentally significant, compression ignition engine, pre ignition, knock ignition, hydrogen safety, hydrogen storage, and anomalous ignition.*

1. Introduction

Mary Helen McCay & Shahin Shafie **[1]** said that Hydrogen is popular for usage in balloons due to its portability and ease of use. As a result, it constitutes 75% of the mass of the universe and is the element with the highest abundance. Because of its reactivity, hydrogen often combines with other elements to produce compounds or the diatomic molecule H_2 . It has a density one-fourth that of air at ambient temperature and pressure and has no discernible flavor, odor, or color. When discharged into the air, it spreads quickly because of its low density. Liquid hydrogen requires cooling to a temperature of 20.3 K. Its high energy density per mass (between 120 and 142 MJ kg-1) has piqued the curiosity of the renewable energy industry as a possible fuel source. Availability in water (H2O), which accounts for around 71% of Earth's surface, is one of hydrogen's greatest selling points Zbigniew Stepie´n **[2]** discussed that There are now a number of methods for creating hydrogen. Methane reformation in steam is now the most widely usedhydrogen-generation method. The production of hydrogen in this situation is both expensive and inefficient (between 65 and 75 percent). Unfortunately, hydrogen also results in significant CO2 emissions. The extensive use of gasification of coal may potentially result in the production of hydrogen. Hydrogen generation efficiency is only around 45%, despite the fact that CO2 emissions are minimal. Hydrogen may also be produced bythe process of water electrolysis.The high price is a result of the method's significant energy usage. In this case, the amount of carbon dioxide emissions varies depending on the kind of electricity source that is used. Hydrogen may result from the microbial conversion of biomass, the liquid reformation of biomass, or the gasification of biomass. Inexpensive and emission-free hydrogen synthesis is possible only with the solar-hydrogen system. VVN Bhasker et al. **[3]** said that There have been four major advancements in engine design using hydrogen fuel. A gas venturi is employed in the first generation. A gas carburetor's intake manifold holds a lot of the fuel-air combination the engine needs to run. The engine must be kept on a low RPM. ($\lambda = 2$) to prevent backfire, which decreases power output. Electronic engine management and multipoint sequential injection are used in second-generation SI engines, much as in gasoline engines.Then, It's possible that the hydrogen would be injected later in the process, after the entering air had cooled the input manifold and the engine's combustion chamber. The third generation maintains stoichiometric ($\lambda = 1$) mixtures even under heavy loads. Exhaust gas recirculation (EGR) may help prevent backfire. Using a three-way catalyst (TWC) at this stoichiometric combination has the potential to lower NOx emissions.Indicated mean effective pressure of 18 bar, as achieved by BMW, shows that turbo/supercharging and inter cooling may increase engine power to levels on par with or greater than gasoline engines which said Berckmüller et al. **[4].** Ford's gas engines are capable of producing torque at 1.85 bar of boost pressure also said Natkin et al. **[5]**. Direct hydrogen injection is being researched for use in next-gen SI engines by many companies, including BMW. **[6 and 7].**

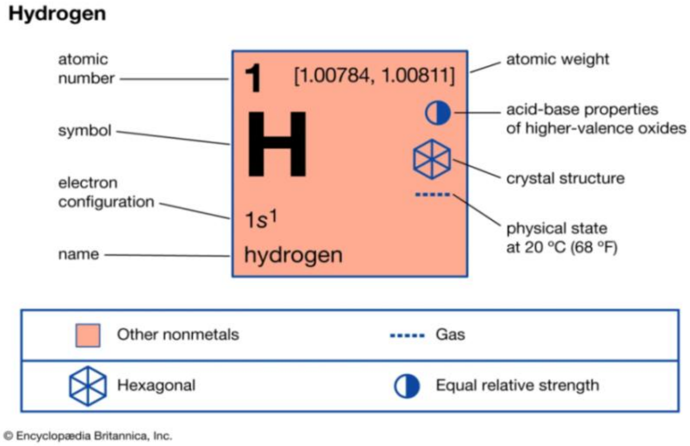


Fig. 1 {Hydrogen} [2]

Literature

Seyed Ehsan Hosseini & Brayden Butler **[8]** analyzed that This century's most serious problem is meeting the world's growing need for energy while also addressing local pollution and global warming. In 2016, national governments throughout the globe reached an agreement that a rise of 2 degrees Celsius in average global temperature was inevitable. Madeleine L. Wright & Alastair C. Lewis **[9]** reached Low or zero-emissions alternatives to fossil fuels are being researched. By 2050, it is expected that renewable energy sources would provide as much as 500% of the world's electrical needs. However, due to current restrictions on weight and space, a need for, or limitation on, a high energy density refueling intervals, some heavy-duty applications cannot employ battery electric power trains. L. Estrada et al. **[10]** analyzed that There is an immediate need to alter the current framework of energy production and consumption, since fossil fuels now provide around 80% of the world's energy requirements. Sanjeevakumar, Khandal et al. **[11]** said Renewable, biodegradable, high-oxygen content, sulfur-free, and cheaper than conventional petroleum fuel products, biofuels have showed promise as a possible replacement.

Most biofuels have 1000hermos-physical properties that are quite similar to those of fossil fuels. The chemical composition of biofuels is lowered after incomplete combustion because of the high-oxygen atoms, resulting in a considerable reduction in smoke, CO, and HC emissions. Vasu kumar et al. **[12]** discussed that Hydrogen is the most common chemical element on our planet.. Our increasingly urgent demand for fossil fuels has led to critically low stockpiles. Temperatures throughout the world are on the increase due to the emission of greenhouse gases like carbon dioxide. The transportation sector has made the development of more efficient engines a top goal. When compared to hydrocarbons, hydrogen's calorific value is much larger. Since it does not enter the food chain or the water supply, it is not a pollutant. Chenglong Tang et al. **[13],** Tang C L, et al. **[30]** conducted experiment where flame speeds fuels that are richer in hydrogen were measured, and it was found that the hydrogen possible 15 m/s speed of the flame, that was nearly five times faster than the methanol flame. PK Bose & D Maji **[31]** investigated how hydrogen affects a diesel engine with 17.5:1 compression. At all loads, the constant hydrogen flow rate was 0.15 kg/h. At 80% power, the thermal efficiency of the brakes is 3.9% better than when using Petro diesel fuel. **[2]** Compared to FC technology, using hydrogen as fuel for ICEs offers significant benefits. Increased resistance to contamination, advances in ICE technology, reduced usage of precious minerals, and ease of converting ICE to hydrogen are some of the most notable.

H_2 Fuel Use in CI Engine

Swain MR et al. **[14]** suggested for Hydrogen engines, in comparison to gasoline engines, have a greater need for proper crankcase ventilation. Diesel engines, like gasoline engines, are susceptible to having unburned fuel leak into the crankcase through the piston rings. Any unburned hydrogen that finds its way into the crankcase is more likely to spontaneously ignite due to the lower energy ignition limit of hydrogen compared to gasoline. Ventilation is key to preventing hydrogen accumulation. If the crankcase catches fire or makes an unusual noise, it might be dangerous. The crankcase pressure increases dramatically when hydrogen ignites. Swain MR et al. **[15]** experimented the pressure might be reduced by using the valve cover's pressure release valve. Hydrogen's volumetric energy density is low when it's at room temperature. Although the fuel's volumetric energy is minimal compared to that of gasoline, liquid storage is possible thanks to cryogenic storage tanks and compressed hydrogen storage tanks. The calorific value of hydrogen is 143 MJ/kg, but the calorific value of gasoline is just 46.9 MJ/kg. It has been looked into whether or not certain crystalline materials can be used for the purpose of storing hydrogen at lower pressures and greater densities.

Szwaja S. & Grab-Rogalinski K. **[16]** Applied Hydrogen is a practical alternative to diesel in IC compression ignition engines for a number of reasons. The fuel's hydrocarbon content rises, which is the first advantage. Second, the high diffusivity of hydrogen may improve the premixing of the combustible mixture with air, making the fuel spray in a diesel engine more homogeneous and reducing the heterogeneity of the spray. Saravanan N. & Nagarajan G. **[17]** analyzed as a result, Hydrogen cannot be used as the only fuel in a compression ignition (CI) engine due to its higher self-ignition temperature and inability to utilize as the sole fuel in such an engine. This means that Avoiding hydrocarbons, CO2, and CO2 emissions is possible. during combustion. Saravanan N et al. **[18]** studied that therefore, Compression ignition (CI) engines cannot use hydrogen without a spark plug. As a result, hydrogen cannot be used in a diesel engine in place of diesel. According to the literature, studies on hydrogen fueling of a diesel engine were founded on dual-fuel mode. In order to ignite the combustion process, a diesel The intake air of a dual fuel engine is fueled in one of three ways: induction, carburetion, or injection. The percentage of pilot fuel to main fuel utilized is debatable, often falling between 10% and 30%. Hydrogen-powered dual-fuel engines may minimize nitrogen oxide emissions and improve thermal efficiency and fuel economy by running at leaner equivalency ratios at part loads.

Hydrogen-powered, dual-fuel engines have a major problem with nitrogen oxides (Nox). Exhaust gas recirculation (EGR) is one approach that has been utilized to successfully lower Nox emissions. Korakianitis T. **[19]** explained Compared to hydrogen dual-fuel running without EGR, volumetric efficiency drops by around 15% as the EGR rate rises. When EGR is utilized in a hydrogen dual-fuel engine, particle emissions may rise compared to when EGR is not used. Smoke emissions from a hydrogen dual-fuel engine using EGR are comparable to those from a traditionally functioning CI engine. Increased emissions of unburned HC, CO, and CO2 arise from using EGR in tandem with reductions in Nox. L.M. Das **[20]** said that Power and efficiency can be maintained in conventional diesel engines that have been adapted for dual-mode hydrogen/diesel operation, with hydrogen meeting 38% of peak power needs.

Air Fuel Ratio

[12]Combustion of hydrogen and oxygen according to stoichiometry may be written as:

$= 2H_2O$

$2H_2 + O_2$

Moles of H_2 for complete combustion = 2 moles

Moles of O_2 for complete combustion = 1 mole

Since nitrogen in the air must be factored in when air is utilized as the oxidizer rather than oxygen calculation

Moles of N_2 in air = Moles of O_2 x (79% N_2 in air / 21% O_2 in air)

= 1 mole of O_2 x (79% N_2 in air / 21% O_2 in air)

3.762 moles N_2

Number of moles of air = Moles of O_2 + moles of N_2

= 1 + 3.762

4.762 moles of air

Weight of O_2 = 1 mole of O_2 x 32 g/mole

32 g

Weight of N_2 = 3.762 moles of N_2 x 28 g/mole

105.33 g ----- (1)

Weight of air = weight of O_2 + weight of N_2 (1)

= 32g + 105.33 g

137.33 g

Weight of H_2 = 2 moles of H_2 x 2g/mole

4 g

Stoichiometric air/fuel (A/F) ratio for hydrogen and air is:

A/F based on mass = mass of air/mass of fuel

= 137.33g /4g

34.33:1

A/F based on volume = volume (moles) of air/volume (moles) of fuel

= 4.762 / 2

= 2.4:1

The percent of the combustion chamber occupied by hydrogen for a stoichiometric mixture:

% H_2 = volume (moles) of H_2 /total volume (2) = volume H_2 / (volume air + volume of H_2)

= 2 / (4.762 + 2)

29.6%

Abnormal Combustion Challenges

[12] Premature ignition is the biggest obstacle to building hydrogen engines. When the fuel-air mixture in the combustion area ignites before the spark plug produces ignition, it is said to have occurred prematurely. The engine loses its optimal performance and starts acting erratically as a result. A backfire may occur in an engine if an unplanned spark happens close the fuel intake manifold and the accompanying flame backflow enters the induction system.Hydrogen and air are sucked into the combustion chamber as soon as the intake valves are opened, where they might catch fire from contact with the chamber's hot surfaces and exhaust gases. Hydrogen has such a low flash point that any residual charge in the ignition system will be enough to set fire to the gas. Therefore, pre-ignition occurs after the flame has been retracted. The one dissimilarity is at the precise moment when it happens. When the intake and exhaust valves shut during the compression stroke, uncontrolled combustion may take place until the spark plug ignites the mixture.Anomalous combustion remains an issue with hydrogen internal combustion engine (ICE) vehicles. The architecture, mixing procedure, or load management of the engine may need to be modified to resolve the issue. The abnormal combustion process typically consists of three stepsengine types that use spark plugs.

The first one is knocking combustion, which occurs when the remaining gas area ignites unexpectedly. The second one type of ignition occurs because of a hot patch and is either pre-ignition or out of control. Backfire and induction ignition are three more names for this event. The suction stroke is the point at which backfire occurs, which is analogous to the early phases of an explosion. Hydrogen-powered engines often experience knocking combustion.The engine might be harmed by the tremendous mechanical and thermal stresses caused by the high amplitude of pressure waves generated by knocking combustion. Hydrogen-powered ICEs are especially vulnerable to the effects of knocking combustion because of the rapid burning rate of the hydrogen mixture.

Using a specialized engine test bench, one may learn about the knock characteristics of a certain fuel (CFR). Using this knocking resistance test bench, we can see how a test fuel stacks up against a blend of iso-octane and heptane. Research octane number (RON) and motor octane number (MON) of the gasoline under the test are determined using the most popular, standardized test for measuring a fuel's resistance to knocking, the CFR engine bench tests.Discordant results are seen when testing the knock resistanceEven near stoichiometric mixes of hydrogen at very high flame rates.Because of this, it is questionable whether or not the conventional approach of measuring knock resistance is applicable here. Internal combustion engines (ICEs) fueled by hydrogen might have their lifetime drastically shortened by knocking combustion. Hydrogen has a wider flammability range, a lower ignition energy, and a shorter quenching distance than other fuels, premature igniting is a considerably more significant concern with hydrogen IC engines.

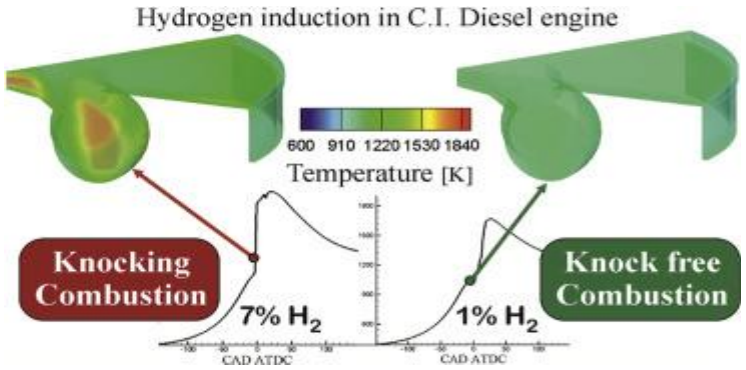


Fig. 2 {Knocking Combustion in Hydrogen} [15]

2. Methods for Producing Hydrogen Fuel

Carburetion of Fuel Method

[12]The most common and conventional method of carburetion is the use of a gas carburetor. For a hydrogen engine, this method has several practical uses. To begin, a lesser hydrogen supply pressure may be sufficient for central injection to work. Second, it is simple to convert a gasoline engine to a hydrogen engine or a hybrid gasoline/hydrogen engine because of central injection or carburetors.When operating on gaseous hydrogen, a carbureted engine loses around 85% of its power, whereas a centrally injected, international combustion engine loses just about 15%. Carburetion can’t be employed in hydrogen-fueled engines because it causes uncontrolled combustion at inconvenient times throughout the engine cycle. Increased hydrogen content in the air drawn into the engine’s Pre-ignition is made worse by the intake manifold. A case of pre-ignition in a premixed engine with the inlet valve open, Intake manifold fires and backfires are possible when gasoline and air mix.

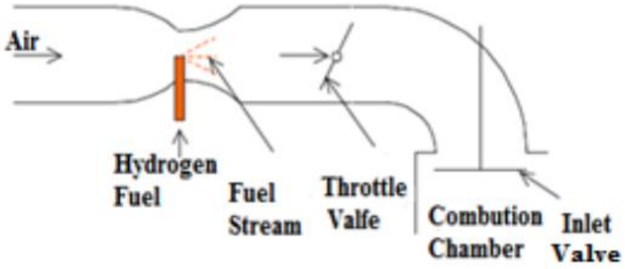


Fig. 3{Carburetion of Fuel Method} [12]

The Intake Manifold method

Fuel injection via a port system do away with the requirement for a centralized fuel pump by injecting fuel into each of the intakes of the manifold by injectors that may be controlled either using machinery or electronic means. At the beginning of intake stroke, hydrogen is often pumped into the manifold. In high-velocity applications, electronic injectors are preferable to mechanical ones because of their longevity, precision adjustment of injection duration, and rapid reaction time.At the start of the intake stroke, air is blown in separately to the port to cool any hot spots and spread the hot residue gases. The consequences of any pre-ignition are minimized since the manifold has a smaller concentration of gas (hydrogen or air). Port injection systems typically have a higher input supply pressure than carbureted or central injection systems and a lower pressure than direct injection systems.Power may be governed by varying the quantity of gasoline released into the atmosphere, whether the engine uses a conventional intake manifold or a port injection system. This allows us to function more effectively. A signal pulse sent to the injector may regulate both the pressure of the hydrogen injection and the length of the injection, allowing for accurate fuel metering.

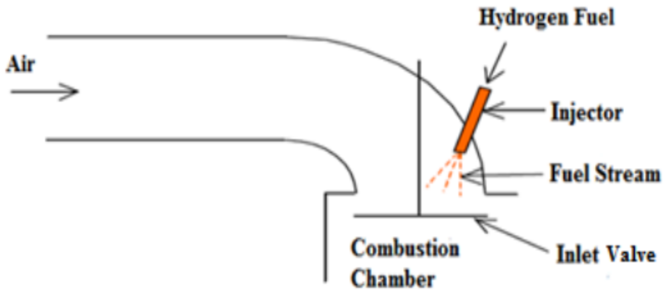


Fig. 4{Intake Manifold Method} [12]

Injection Directed Method

The combustion chamber is filled with hydrogen at high pressure immediately after the compression stroke is complete. Due to its quick dissipation, hydrogen burns immediately when mixed. The ignition may be sparked by diesel fuel or a spark plug.The power loss caused by manifold induction/injection may be reduced, if not eliminated, when direct spark ignition is used in each cylinder. Engine efficiency may reduce somewhat at stationary or partial load. While not ideal, this is currently the most viable strategy for exploiting hydrogen. a fuel cell's output of energy by splitting hydrogen. The price of this engine was 42% more than that of a hydrogen engine with a carburetor, and 20% higher than that of a gasoline engine. Hydrogen injected directly into the combustion chamber of a compression ignition (CI) engine would roughly quadruple the engine's power output when compared to the identical engine running in pre-mixed mode. Due to hydrogen's high combustion stoichiometric heat per kilogram of air, such an engine would produce more power than a fuel-powered engine (Hydrogen has around 3.37 MJ, but gasoline only has 2.83 MJ). Although preignition is never allowed to occur in the intake manifold when direct injection is used, this does not necessarily hold true for the combustion chamber. A direct injection engine would also produce an uneven mixture of air and fuel due to the shorter time needed for the two to combine.

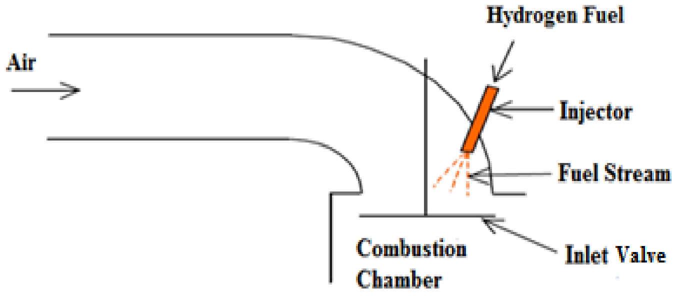
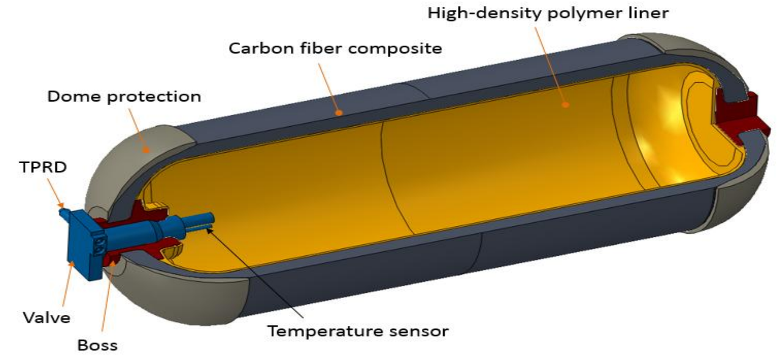


Fig. 5 {Direct Injection Method} [12]

H_2 Storage Tank

Wen-Chey Chang et al. **[21]** analyzed that Hydrogen has to be stored in manufacturing plants, gas stations, vehicles, and as a national strategic reserve if we're going to have a hydrogen economy. Schlapbach & Züttel **[22]** discussed the lack of a reliable mechanism to store hydrogen as the single largest challenge facing the hydrogen economy. The development of suitable storage infrastructure is essential for the introduction of a hydrogen transportation economy. Hydrogen's negligible density means it must be carried in a massive on-board tank. An internal combustion engine (ICE) requires a hydrogen cylinder weighing 8 kg to provide the same range as a standard automobile (about 400 kilometers). Hirscher et al **[23]** experimented that Research into nanostructures has increased dramatically after it was found that carbon nanotubes might be utilized to store hydrogen. Seyed Ehsan Hosseini & Brayden Butler **[8]** analyzed that Physiochemical or chemical therapies may be used to keep hydrogen in either its solid or liquid state. Materials including boron materials, chemical hydrides, materials based on carbon, magnesium-based alloys, and metallic hydrides have all been tried in hydrogen storage devices with varying degrees of success. There are six distinct methods to store hydrogen.

a. Cryogenic hydrogen (at a temperature of 21 K) storage tanks.
b. Adsorbed in the cracks and crevices of the host metal under room temperature and pressure.
c. Compounds formed through covalent and ionic bonding (at room temperature and pressure).
d. Storing gas at high pressures (up to 800 Bar) in cylinders.
e. Hydrogen adsorption (at T 100 K) on high specific surface area materials.
f. Metals including lithium, sodium, magnesium, aluminum, and zinc are prone to oxidizing in water.



TPRD = Thermally Activated Pressure Relief Device
Credit: Process Modeling Group, Nuclear Engineering Division. Argonne National Laboratory (ANL)

Fig. 6{Compressed Hydrogen Storage System} [17]

Safety of H_2 Vehicle

Singh et al. **[24]** discussed that Fuels having high specific heat and a low density are the most dependable. If you put in the same amount of heat but have a greater specific heat, you can only reduce the temperature by a smaller amount. Fuels with larger ignition limits and lesser ignition temperatures, for example, are safer because they allow for a larger range of fire scenarios to occur. More destructive fires and riskier fuel are the consequence of higher explosive energy and higher flame emissivity. Veziroglu T. & Sahin S. **[25]** showed that **Table 1** summarizes gasoline, methane, and hydrogen all provide a significant fire risk. Sharma & Ghoshal **[26]** said that Hydrogen presents minimal risk of combustion or explosion because of its low density (approximately 6.9% that of air), strong diffusion (4 times that of NG and 12 times that of gasoline), and a lack of combustibility. Hawkins & Hughes **[27]** Suggested Hydrogen is a non-toxic gas; thus any leaks wouldn't have any negative effects on the environment. A hydrogen/air mixture that gets a spark is far more likely to result in a fast-burning fire than an explosion of hydrogen since hydrogen explosions are so difficult to make. Alazemi & Andrews **[28]** specified Hydrogen has the advantage of burning has little thermal radiation, so that only objects directly in the flame's path are damaged.. Midilli et al**.**

[29] said that Clear flames can't sear skin at a distance because they don't put out enough heat. Hydrogen is a threat because even small concentrations may ignite. The US Department of Energy has defined requirements for safe storage and system operation. There has to be SAE J2579 compliance with regards to leakage and permeation testing, acceptable toxicity standards, failure analysis, and overall system evaluation. All of the components of the storage system, not only the media itself, are subjected to permeation and leakage testing. The EPA, together with the Occupational Safety and Health Administration (OSHA), and the Toxic Substances Control Act Chemical Substance Inventory (TSCA Inventory), determine the acceptable toxicity threshold. Everything from the design of the transportation network itself to the manufacture, authorization, and operation of cars to the sale of fuel and the disposal of obsolete vehicles must adhere to the safety criteria, which are based on federal, state, and local legislation. SAE J2579, UN Global Technical Regulation No. 13, and local legislation all need to be met by the vehicle's on-board storage systems.

PROPERTY	GASOLINE	METHANE	HYDROGEN
Density (kg/m)	4.4	0.65	0.084
Diffusion coefficient in air (cm2/s)	0.05	0.16	0.61
Specific heat at constant pressure (j/gk)	1.2	2.22	14.89
Ignition limits in air (vol %)	1.0 –7.6	5.3 –15	4.0 –75
Ignition energy in air (Mj)	0.24	0.29	0.02
Ignition temperature (°c)	228–471	540	585
Flame temperature in air (°c)	2197	1875	2045
Explosion energy (gtnt/kj)	0.25	0.19	0.17
Flame emissivity (%)	34 – 43	25 – 33	17 – 25
• **It was a standard room temperature and pressure.** • **Theoretical upper limit; real value is 10% of that.**			

Table 1 {Different Fuels for Vehicles Pose Different Fire Risks}

Study of The Objectives

a. To investigate the performance analysis, environmental impact, and combustion characteristics of various flow rates in various loads with hydrogen as a additive gas with diesel fuel.
b. The goal is to determine the optimal hydrogen gas flow rate that maximizes brake thermal efficiency while simultaneously minimizing engine-out emissions.
c. To investigate the performance analysis, environmental impact, and combustion characteristics of best flow rate of hydrogen as an additive gas with diesel fuel combustion under varied operating parameters such as diesel fuel injection time and pressure, diesel fuel temperature, intake air temperature, cooling water flow rate, and diesel fuel injection time and pressure in combination.
d. The objective of this study is to identify and evaluate the operational parameters of a diesel engine that regulates the combustion of hydrogen gas.

3. Methodology of The Study

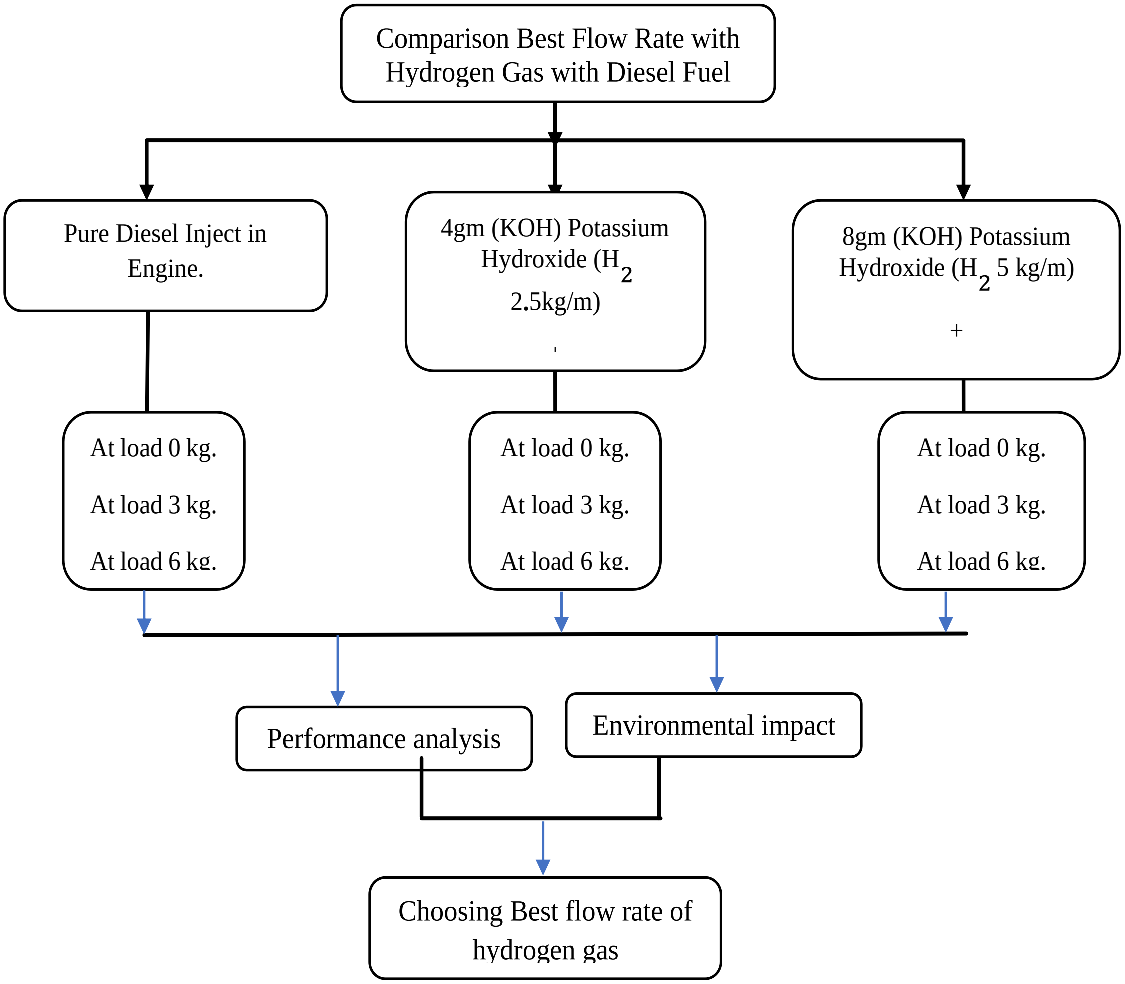


Fig 7. Research Methodology for Finding Best Flow Rate of Hydrogen

Procedure and Experimental Setup

The experimental setup with necessary instruments to evaluate the performance analysis, and environmental effect of the diesel engine at different operating parameters is shown in **Figure 8**. In this chapter, the instruments which were used in the experiments and the experimental procedures followed in this study are detailed.

Engine Description

Kirloskar engines are one of the most popular brands for usage in the farming industry. They are also utilized in mining, construction, and the automobile industry, among other heavy industrial uses. To reduce wear on the piston liner, these engines have a centralized chamber in the piston design and an oil jet spray that is always active (Kirloskar, 2014). Low cylinder bore distortion at high in-cylinder pressures is another benefit of the engine's robust design. In addition, the cylinder head and piston crown are less complicated places to undertake repairs. The present experimental investigation was conducted in a Kirloskar make single cylinder, having power 5.20 kW @ 1500 rpm which is 1 Cylinder, four stroke, Constant Speed, Water Cooled, Diesel Engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm), Compression Ratio 18.00, Swept volume 661.45

(cc). The experiment were conducted at a constant speed of 1500 rpm with variable load. The load varied from no load to maximum load (from 0% to 100% of the engine's rated load in 25% increments). Manufacturer recommendations for operational parameters such diesel fuel injection time and pressure are 23degree BTDC. The engine speed was adjusted using the governor. Water was pumped via jackets in the engine block and cylinder head to cool the internal combustion engine. The in-cylinder pressure was determined by installing a piezoelectric pressure transducer in the cylinder head. An eddy current dynamometer was linked to the engine for loading purposes.

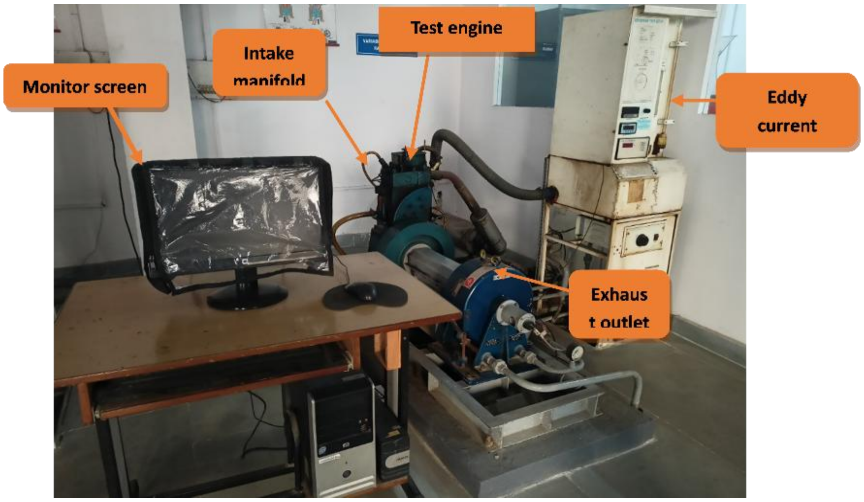


Fig 8. Photographic view of experimental set up

Fig 9. Photographic View of Hydrogen Gas Induction Point

4. Results and Discussion

Choosing the Best Flow Rate of Hydrogen Gas

Hydrogen gas flow rate comparisons in terms of efficiency, emissions, and combustion: At first, the engine was run on pure diesel fuel with the typical injection time (23 degrees before top dead center), injection pressure (200 bars), compression ratio (17:1), and speed (1500 revolutions per minute). The findings of additional tests may be compared to this standard procedure. The engine's optimal flow rate of Hydrogen gas was determined in the second and third phases of testing by considering the facts of increased thermal efficiency and decreased engine-out emissions. For this, the hydrogen gas flow rate 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg). Electrolyzed water molecules, combined with the intake air required by the engine's regular operating conditions, were sucked into the cylinder. The following sections detail the most important findings from the current experimental inquiry.

a. Brake Thermal Efficiency

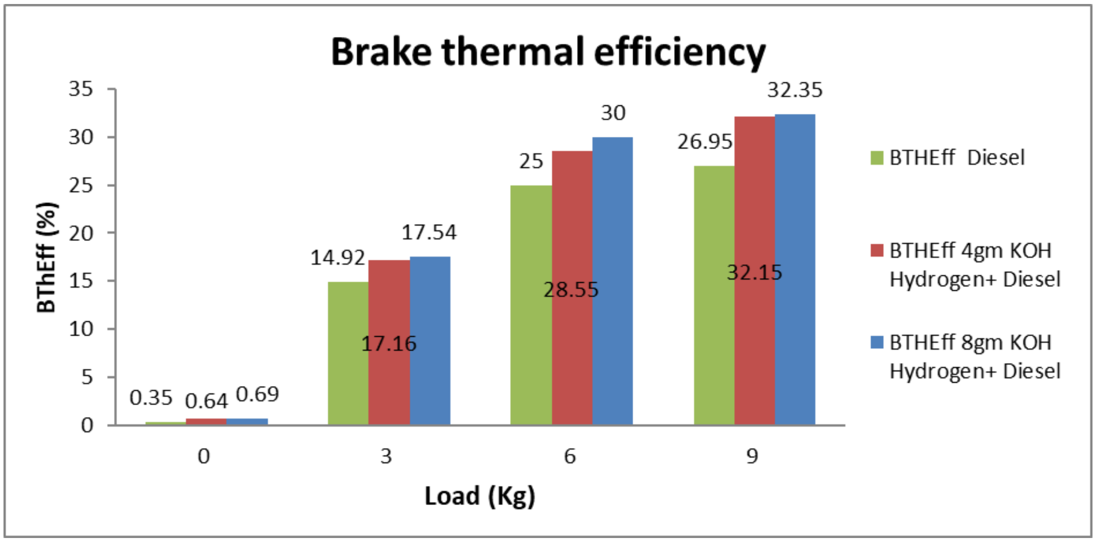


Fig 10. Comparison of BTE for pure diesel anddiesel with Hydrogen gas at various load

Fig.10 shows the comparison of brake thermal efficiency for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specifications. An engine's brake thermal efficiency is measured as the ratio of braking power output to chemical energy input from fuel. The thermal efficiency of the brakes was determined using the following equation:

$$Brake\ thermal\ efficiency = \frac{BP}{m_f \times LCV}$$

analyzing the graph, it should be concluded that the brake thermal efficiency increased when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load, the brake thermal efficiency for base line operation was 26.95%, whereas it increased by 5.2% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 5.55% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.The inclusion of atomic hydrogen and oxygen in the gas combination, together with the mixture's high flame velocity, contributed to the improvement in brake thermal efficiency.

b. Indicated Thermal Efficiency

Fig. 11 shows the comparison of Indicated thermal efficiency for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specificationsan engine's indicated thermal efficiency is measured as the ratio of indicated power to the fuel power generated through combustion. The indicated thermal efficiency was determined using analyzing the graph, it should be concluded that the indicated thermal efficiency increased when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load, the indicated thermal efficiency for base line operation was at engine load is 51.17%. whereas it increased by 16.44% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 20.29% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.The inclusion of atomic hydrogen and oxygen in the gas combination, together with the mixture's high flame velocity, contributed to the improvement in indicated thermal efficiency.

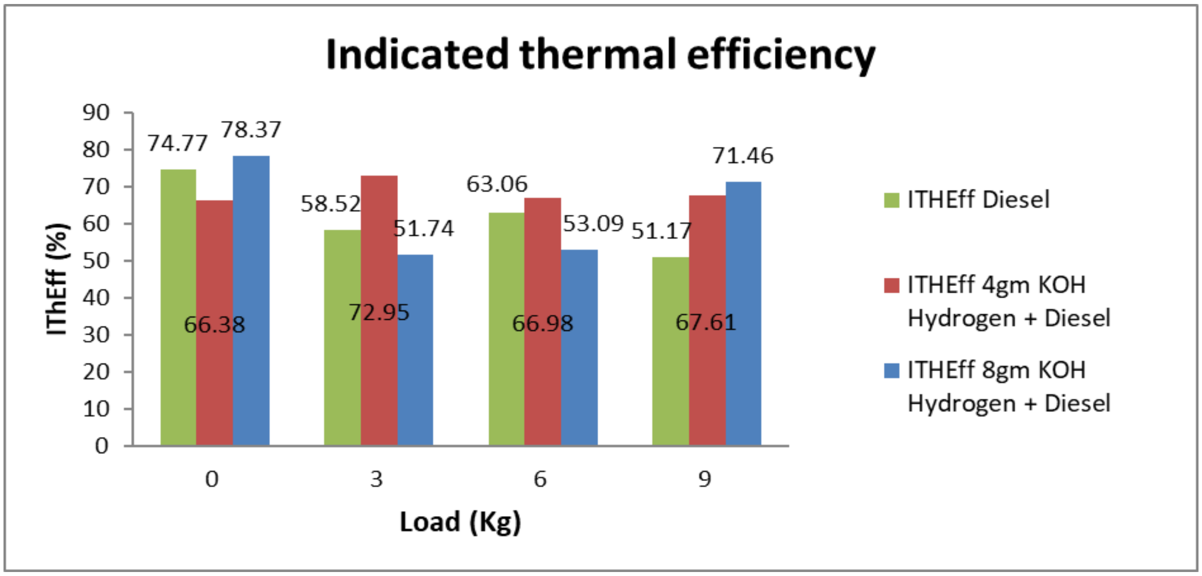


Fig 11. Comparison of ITE with pure diesel and diesel with Hydrogen gas at various load

c. Mechanical Efficiency

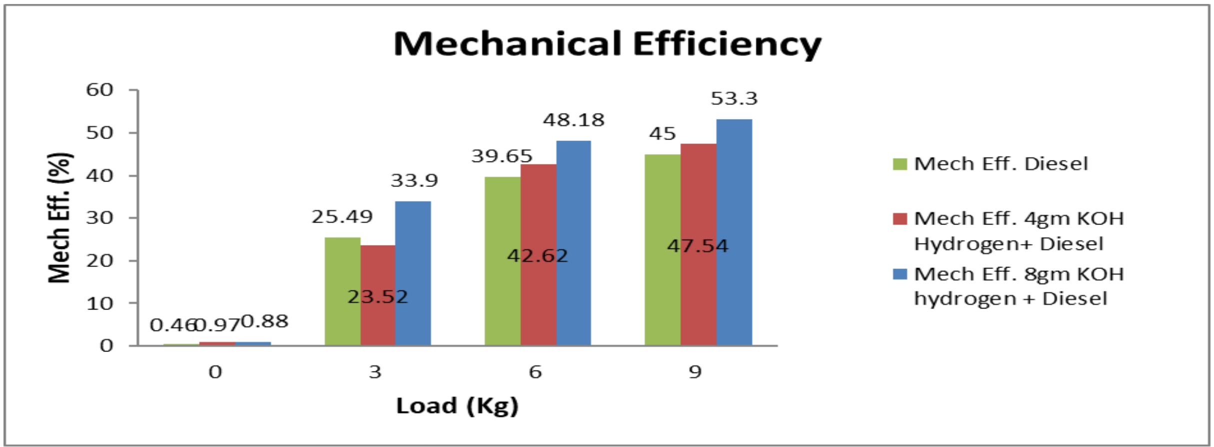


Fig 12. Comparison of Mech. Eff. with pure diesel and diesel with Hydrogen gas at various load

Fig. 12 shows the comparison of mechanical efficiency for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specificationsan engine's Mechanical efficiency is measured as the ratio of machine converts input energy work to the power into the output energy. The Mechanical efficiency was determined using analyzing the graph, it should be concluded that the mechanical efficiency increased when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the indicated thermal efficiency for base line operation was at engine load is 45%. whereas it increased by 2.54% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 8.3% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.The inclusion of atomic hydrogen and oxygen in the gas combination, together with the mixture's high flame velocity, contributed to the improvement in Mechanical efficiency.

d. Torque

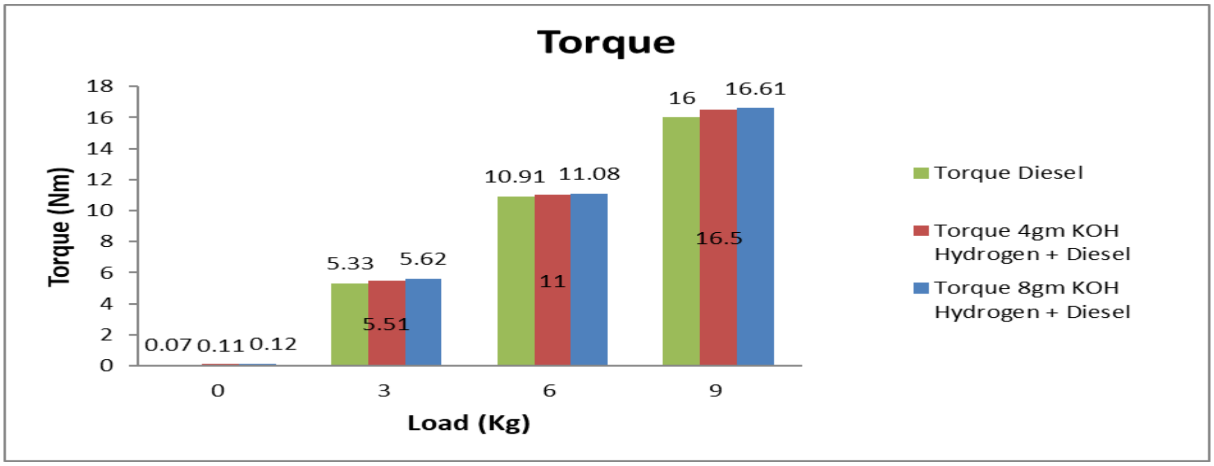


Fig 13. Comparison of Torque with pure diesel and diesel with Hydrogen gas at various load

Fig. 13 shows the comparison of Torque for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specificationsan engine's torque is measure of the force that can cause an object to rotate about an axis. analyzing the graph, it should be concluded that the torque increased when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the Torque for base line operation was at engine load is 16%. whereas it increased by 0.5% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 0.61% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.The inclusion of atomic hydrogen and oxygen in the gas combination, together with the mixture's high flame velocity, contributed to the improvement in Torque.

e. Air

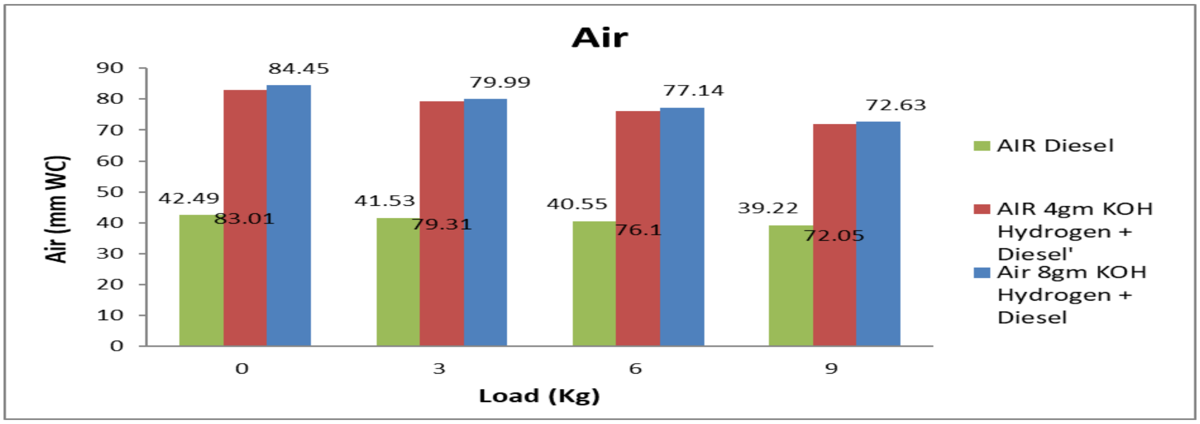


Fig 14. Comparison of Air with pure diesel and diesel with Hydrogen gas at various load

Fig. 14 shows the comparison of Air for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specificationsan engine that uses the expansion of heated air to drive a piston.analyzing the graph, it should be concluded that the air increased when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the Torque for base line operation was at engine load is 39.22%. whereas it increased by 32.83% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 33.41% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.The inclusion of atomic hydrogen and oxygen in the gas combination, together with the mixture's high flame velocity, contributed to the improvement in suction air.

f. Fuel Consumption

Fig. 15 shows the comparison of Fuel consumption for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specifications.the amount of fuel a vehicle uses to travel a particular distance at a particular speed.analyzing the graph, it should be concluded that Fuel consumption decreased when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the Fuel consumption for base line operation was at engine load is 0.85%. whereas it Decreased by 0.15% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 0.15% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.

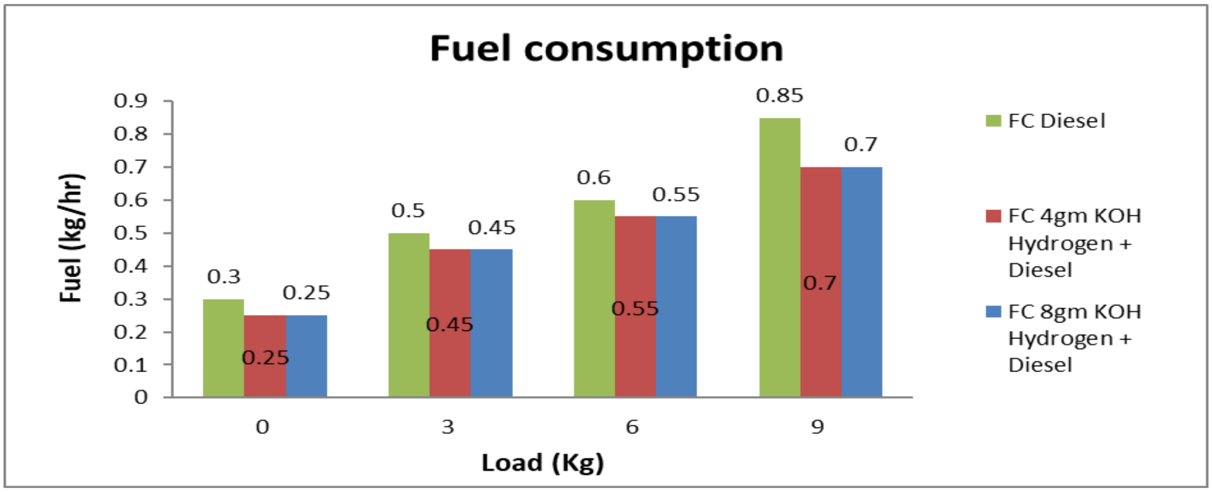


Fig 15. Comparison of Fuel consumption with pure diesel anddiesel with Hydrogen gas at various load

g. Carbon monoxide Emission

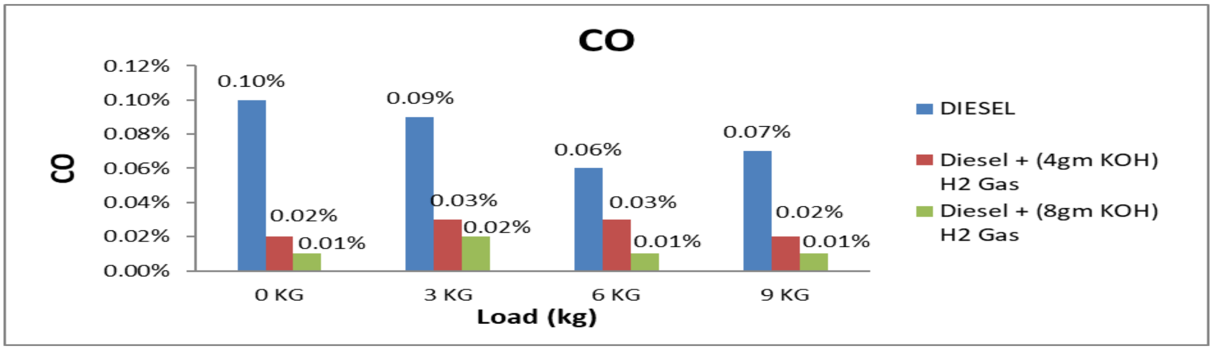


Fig 16. Comparison of carbon monoxide with pure diesel and diesel with Hydrogen gas at various load

Fig. 16 shows the comparison of carbon monoxidefor pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specifications. analyzing the graph, it should be concluded that the carbon monoxide Emission when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the carbon monoxide emission for base line operation was at engine load is 0.07%. whereas it Decreased by 0.05% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 0.06% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.

h. Carbon Dioxide Emission

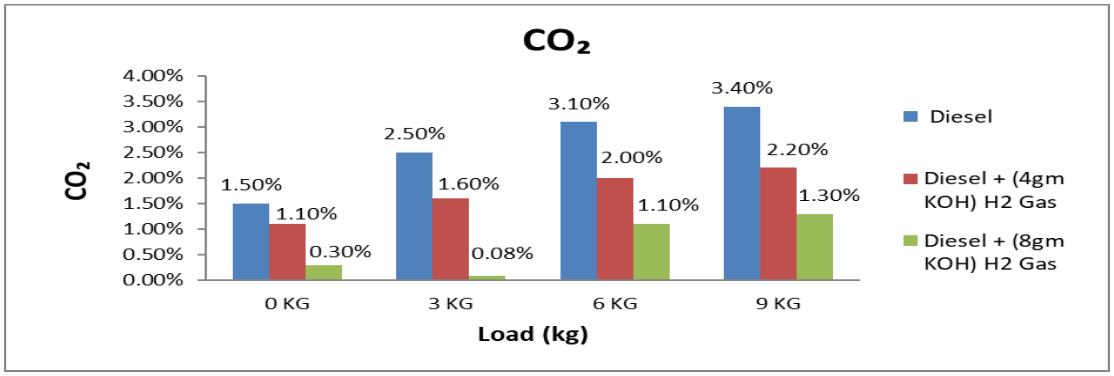


Fig 17. Comparison of carbon dioxide with pure diesel and diesel with Hydrogen gas at various load

Fig. 17 shows the comparison of carbon dioxide for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specifications. analyzing the graph, it should be concluded that the carbon dioxide Emission when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the carbon dioxide emission for base line operation was at engine load is 3.40%. whereas it Decreased by 1.2% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 2.1% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.

i. Oxygen Emission

Fig. 18 shows the comparison of oxygen emission for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specifications.analyzing the graph, it should be concluded that the oxygen Emission when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the oxygen emission for base line operation was at engine load is 15.58%. whereas it increased by 1.78% when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 4.85% when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.

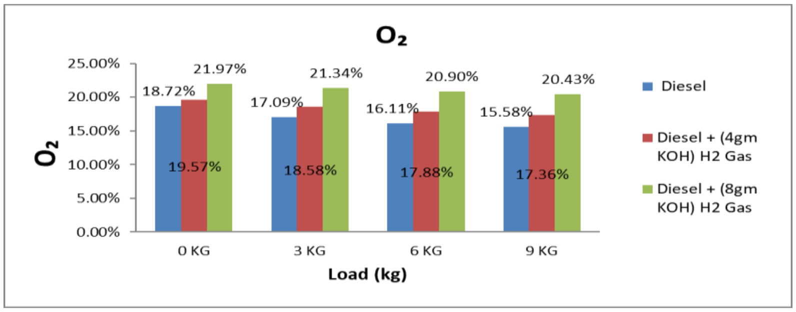


Fig 18. Comparison of oxygen with pure diesel anddiesel with Hydrogen gas at various load

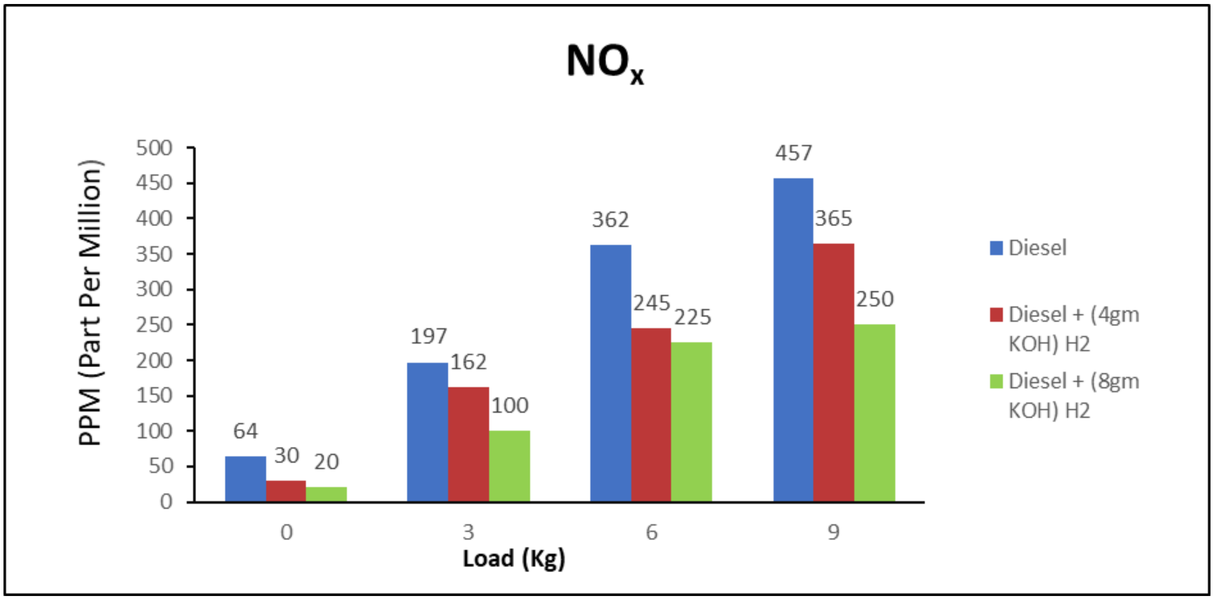


Fig 19. Comparison of Nitrogen oxide with pure diesel anddiesel with Hydrogen gas at various load

j. Nitrogen Oxide Emission

Fig. 19 shows the comparison of Nitrogen oxide for pure diesel and diesel with Hydrogen gas 2.5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) and 5 (m^3/min) at engine load (0kg), (3kg), (6kg), (9kg) at standard engine specifications.analyzing the graph, it should be concluded that the nitrogen oxide Emission when Hydrogen gas was used as a combustion stimulant, compared to base line operation. At 100% rated load (9kg), the Nitrogen oxide emission for baseline operation was at engine load is 457 PPM. whereas it decreased by 92PPM when 4gm KOH mix in water at flow rate 2.5 (m^3/min) and 207 PPM when 8gm KOH mix in water at flow rate 5 (m^3/min) was added in the diesel combustion process.

5. Conclusion

- Hydrogen Gas Is a Supplementary Fuel Used in Experiments; It Has the Potential to Boost CI Engine Output. Here, The Influence of Hydrogen Gas and Compression Ratio on Diesel Engine Performance Is Investigated in A Single Experiment.
- This Experiment Measures the Effect of Different Loads With 1500 revolutions per Minute at Dual Fuel Operation with a Compression Ratio of 17:1.
- At 2.5 M^3/Min the Dual Fuel Injecting Engine Intake Manifold of the Engine Is Better Perform Than Pure Diesel Combustion in Engine.
- At 5 M^3/Min the Dual Fuel Injecting Engine Intake Manifold the Engine Is Better Perform Than Pure Diesel And 2.5 M^3/Min Dual Fuel Combustion in the Engine.
- The Emission of Dual Fuel Operation Was Effective on Engine.

Nomenclature:

H_2 - Hydrogen

H_2O - Water

CO_2 - Carbon Dioxide

(λ) – Lean Mixture

EGR – Exhaust Gas Recirculation

TWC - Three Way Catalyst

BMW – Bavarian motor works

CO – Carbon Monoxide

HC - Hydrocarbon

ICE – Internal Combustion Engine

H/C – Hydrogen/ Carbon Atoms

CI – Compression Ignition

Nox – Nitrogen Oxides

CFR – Cooperative Fuel Research

RON – Research Octane Number

MON – Motor Octane Number

DI – Direct Injection

MJ – Mega Joule

Km - Kilometer

Mg - Magnesium

Li - Lithium

Na - Sodium

Al - Aluminum

Zn - Zinc

K - Kelvin

NG – Noise Gain

US – United States

DOE – Department Of Energy

SAE – Society of Automotive Engineers

TSCA - Toxic Substances Control Act

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